

## ORIGINAL RESEARCH

## INTRA AND INTERSESSION RELIABILITY OF A POSTURAL CONTROL PROTOCOL IN ATHLETES WITH AND WITHOUT ANTERIOR CRUCIATE LIGAMENT RECONSTRUCTION: A DUAL-TASK PARADIGM

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## ABSTRACT

**Background:** Quantification of dynamic balance is essential to assess a patient's level of injury or ability to function so that a proper plan of care may commence. In spite of comprehensive utilization of dual-tasking in balance assessment protocols, a lack of sufficient reliability data is apparent.

**Purpose:** The purpose of the present study was to determine the intra- and inter-session reliability of dynamic balance measures obtained using the Biodex Balance System® (BBS) for a group of athletes who had undergone anterior cruciate ligament reconstruction (ACLR) and a matched control group without ACLR, while using a dual-task paradigm.

**Methods:** Single-limb postural stability was assessed in 15 athletes who had undergone ACLR and 15 healthy matched controls. The outcome variables included measures of both postural and cognitive performance. For measuring postural performance, the overall stability index (OSI), anterior-posterior stability index (APSI), and medial-lateral stability index (MLSI), were recorded. Cognitive performance was evaluated by measuring error ratio and average reaction time. Subjects faced 4 postural task difficulty levels (platform stabilities of 8 and 6 with eyes open and closed), and 2 cognitive task difficulty levels (with or without auditory Stroop task). During dual task conditions (conditions with Stroop task), error ratio and average reaction time were calculated.

**Results:** Regarding intrasession reliability, ICC values of test session were higher for MLSI [ACLR-R group (0.83-0.95), control group (0.71-0.95)] compared to OSI [ACLR-R group (0.80-0.92), control group (0.67-0.95)] and APSI [ACLR-R group (0.73-0.90), control group (0.62-0.90)]. Furthermore, ICC values of first test session were higher in reaction time [ACLR-R group (0.92-0.95), control group (0.80-0.92)] than error ratio [ACLR-R group (0.72-0.88), control group (0.61-0.83)]. ICC values of retest session were higher for MLSI [ACLR-R group (0.83-0.94), control group (0.87-0.93)] than OSI [ACLR-R group (0.81-0.91), control group (0.83-0.93)] and APSI [ACLR-R group (0.73-0.90), control group (0.53-0.90)]. Moreover, ICC values of retest session were higher in reaction time [ACLR-R group (0.89-0.98), control group (0.80-0.92)] equated with error ratio [ACLR-R group (0.73-0.87), control group (0.57-0.79)].

With respect to intersession reliability, ICC values were higher for MLSI [ACLR-R group (0.72-0.96), control group (0.75-0.92)] than OSI [ACLR-R group (0.55-0.91), control group (0.64-0.87)] and APSI [ACLR-R group (0.55-0.79), control group (0.46-0.89)]. Additionally, ICC values were higher in reaction time [ACLR-R group (0.87-0.95), control group (0.68-0.81)] in contrast to error ratio [ACLR-R group (0.42-0.64), control group (0.54-0.74)].

**Conclusion:** Biodex Balance System® measures of postural stability demonstrated moderate to high reliability in athletes with and without ACLR during dual-tasking. Results of the current study indicated that assessment of postural and cognitive performance in athletes with ACLR may be reliably incorporated into the evaluation of functional activity.

**Level of Evidence:** 2b

**Key words:** Anterior cruciate ligament reconstruction, attention, Biodex Balance System®, dual-task paradigm, reliability

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## Statement of the Institutional Review Board Approval:

Informed consent form approved by the Ethics Committee at University of Social Welfare & Rehabilitation Sciences.

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## INTRODUCTION

Injuries to the anterior cruciate ligament (ACL) are common in the athletic population.<sup>1,2</sup> Anterior cruciate ligament reconstruction (ACLR) has been shown to be successful in restoring knee stability and function.<sup>3</sup> However, the implantation of a substitute for the ACL does not adequately restore the sensorimotor system, which may result in a compromised afferent neural system.<sup>4</sup> According to multiple authors, a deficient or reconstructed ACL causes biomechanical alterations,<sup>5,6</sup> as well as decreases in muscular strength<sup>7,8</sup> and function<sup>5,9</sup> such as quadriceps inhibition.<sup>10</sup> Furthermore, knee proprioceptive functions are affected by an ACL reconstruction/deficiency.<sup>11-15</sup> The ACL provides important sensory information that mediates joint position sense, provides information regarding the threshold for detection of motion, and coordinates muscular reflex stabilization about the knee joint. A deficit in joint position sense, a higher threshold for detection of passive knee motion, and a longer latency of hamstring muscle activation have all been observed in individuals who have sustained an ACL injury and also in those who have undergone reconstruction.<sup>12</sup> These sensory deficits seem to lead to decreased motor performance. Although decreased static postural control has been reported in ACL-R individuals,<sup>4,12</sup> dynamic postural control in these individuals has been minimally evaluated.<sup>4</sup>

Postural stability has been defined as the ability to maintain the center of body mass (COM) over the base of support.<sup>16</sup> The ability to maintain the COM within the base of support under dynamic conditions is an essential underlying component of physical activity.<sup>17</sup> Although postural control is traditionally considered to be automatic, therefore requiring minimal information processing, Siu and Woollacott<sup>18</sup> have shown that the process of maintaining or regaining postural stability requires remarkable information-processing (a cognitive task). The attentional demand needed for regulating postural sway is typically examined using the dual-task paradigm, which presumes that cognitive functions and postural control compete for limited attentional capacity.<sup>19</sup> Attention is defined as the degree of focus or concentration on a specific task and its capacity is limited. People can only focus on a small number of things at the same time. If the amount of information that needs to be processed by CNS increases, motor performance may be decreased.<sup>16</sup>

Thus, dynamic knee stability may be at greater risk when a given functional task is more complex than during a simpler task. This is because the complexity and attentional demands associated with the complex task are significantly more than during a simple task. It is no surprise that athletes often sustain ACL injuries in complex situations. The role of attention in sensorimotor control, injury, and training has been understudied in the past but currently has begun to receive greater consideration.<sup>20</sup> Therefore, application of dual-task paradigm in assessment of patients with ACL injuries and reconstructions may be helpful throughout recovery.

Among the devices capable of quantifying measurements of dynamic postural stability, the Biodex Balance System® (BBS) is reported to be able to reliably assess a patient's neuromuscular control during closed-chain lower extremity tasks.<sup>19,20</sup> The BBS® uses a circular platform that moves freely in the anterior-posterior (AP) and medial-lateral (ML) axes simultaneously and it has been extensively used to evaluate postural stability in recent years.<sup>21,22</sup> Although evidence supports importance of assessing the accuracy of balance equipment such as the BBS® for measuring dynamic balance,<sup>21-23</sup> the reliability of dynamic balance measures provided by the BBS® remains unclear in subjects with and without ACLR with respect to dual-task methodology. Therefore, the purpose of the present study was to determine the intra- and inter-session reliability of dynamic balance measures obtained using the Biodex Balance System® (BBS) for a group of athletes who had undergone ACLR and a matched control group without ACLR, while using a dual-task paradigm.

## METHODS

### Participants

A total of 30 athletes voluntarily participated in this study. They were matched according to age, sex, height, weight, and level of physical activity (according to Tegner's sport activity level).<sup>24,25</sup> Fifteen individuals with ACLR (mean time since surgery  $12 \pm 6$  months) were recruited. The ACLR group included 1 female and 14 males with a mean age of  $26.00 \pm 7.31$  years, height of  $174.58 \pm 5.84$  cm, weight of  $80.24 \pm 10.61$  kg, and the Tegner activity score of  $5.74 \pm 2.51$ . The matched control group included 1 female and 14 males of mean age  $23.37 \pm 6.50$  years,

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height  $172.69 \pm 5.37$  cm, weight  $77.87 \pm 9.46$  kg, and the Tegner activity score  $6.58 \pm 1.93$ .

All ACLR surgeries were performed in a similar fashion (arthroscopically assisted anatomic double-bundle anterior cruciate ligament reconstruction using autogenous hamstring tendons). Subjects in the ACLR group were pain free, full weight bearing, functionally stable, had normal gait at the time of study, and were cleared by the orthopedic surgeon for participation in this study. Healthy athletes who reported no history of any substantial orthopedic injury or balance-related disorders served as the control group. Substantial orthopedic injury was defined as an injury with symptoms persisting for longer than 2 weeks.

Both control and ACLR individuals were excluded if they had any balance, vestibular or visual problems, or a significant injury to either lower extremity other than the ACL rupture or if they had injured any other knee ligaments at the time of the ACL rupture over the last year. Individuals who had undergone minor non-surgical meniscal treatment, whose pain and other symptoms with utilization of anti-inflammatory medications and cold packs applied to the knee ceased within two or three weeks after injury, were included. The side tested for those in the control group was matched to the involved side of those in the ACLR group. Subjects were briefed on all testing procedures and asked to read and sign a consent form approved by Ethics Committee of the University of Social Welfare and Rehabilitation Sciences. Also, subjects completed a questionnaire before being tested, that included demographic and injury information, through which the exclusion criteria were reviewed.

### Postural Task

The Biodex Balance System® (BBS) (Biodex Medical Systems, Shirley, NY) was used to assess postural performance. The BBS® is a multiaxial device that objectively measures and records the ability of individual to maintain posture under dynamic stress. Unlike force plate systems, the BBS® uses a circular platform, which is free to move in the anterior-posterior and medial-lateral directions simultaneously.<sup>21</sup> The BBS® calculates a medial-lateral stability index (MLSI), an anterior-posterior stability index (APSI), and an overall stability index (OSI). These indices are variances of displacement measures and

represent fluctuations around a zero point established prior to testing when the platform is stable.<sup>21</sup> The BBS® software samples the degree of tilt from level in the medial-lateral (X) and anterior-posterior (Y) directions at a frequency of 20 Hz.<sup>21</sup> Stability scores were calculated by the BBS® computer interface and then manually copied and entered into a statistical software package (SPSS, Version 15).

Higher scores on the stability indices indicate a greater amount of postural variability, hence decreased postural stability. The difficulty of the postural stability task can be varied from stability level 8 to stability level 1. Level 8, which is the highest level of stability, allows the platform to be least easily tilted and therefore makes it easier for subjects to maintain stability. Level 1, which is the lowest level of stability, allows the platform to be most easily tilted and makes it more difficult for subjects to maintain stability.<sup>16</sup> It is possible to adjust the stability of the system by changing the resistance force applied by springs to the underside of the platform.<sup>26</sup> So, the lower the stability level (resistance force) the less stable the platform.<sup>22</sup>

In the present study, the subjects were tested at two Biodex® stability levels: levels 8 and 6, based upon a pilot study conducted by the authors. The results of this preliminary study demonstrated that the ACLR participants were typically unable to complete the test at lower levels of stability when standing on their affected limb (stability level settings lower than 6). Participants were asked to stand on the involved limb (or in the case of the controls, the limb matched to the ACLR limb of their paired subject) on the BBS® platform with their eyes open and then closed for 30 seconds during each trial. During eyes open conditions, the participants were asked to look straight at a small piece of paper on the wall at their eye level.<sup>27</sup> During eyes closed conditions, participants wore a blindfold to eliminate visual feedback. The unsupported foot was placed behind the weight-bearing ankle during testing (Figure 1). Participants stood barefoot with both hands placed upon the iliac crests. Next, participants were instructed to adjust the position of the supporting foot until they found a position where they were able to maintain platform stability. The platform was then locked and the subject's foot position coordinates were marked on the platform as an array of (X, Y) coordinates and recorded by the





**Figure 1.** Test condition on the Biodex Balance System (BBS) during dual task performance.

examiner.<sup>27</sup> The angle of the third metatarsal in reference to the Y-axis was also recorded manually.<sup>16</sup> The subjects were instructed not to move their test foot from the platform throughout test trials as the examiner altered the experimental conditions between difficulty levels. Subjects repeated the trial if they put their non-weightbearing foot down or if they touched the handrails with their arms during the test.<sup>22</sup>

### Cognitive Task

An auditory version of the Stroop task was used. In this task, the subjects were presented the Persian equivalents of the words “high” and “low” in either a high or low tone pitch.<sup>28</sup> The participant was asked to verbally respond with the word which was reversely correspondent to the heard pitch as quickly and accurately as possible, regardless of the word meaning, during a 30 second trial. Congruency between pitch and the word was randomized. Error ratio (number of errors/number of auditory signals) and the average reaction time were recorded during each trial.

Verbal reaction times (VRT) during Stroop tasks were calculated from the time difference between auditory stimulus onset and the onset of the verbal response.<sup>29</sup> The program used during the auditory Stroop task was written by a programmer and implemented by Matlab® (R2010A, Mathworks, Navick, MA, USA) software, with stimuli relayed via a wireless headset (SHB6111, Koninklijke Philips Electronics NV, China). Verbal responses to the auditory stimuli were recorded through a wireless microphone (NP-101, LEM, Taiwan). The response time of each word was recorded by Matlab® software in the Microsoft Office Excel 2007. Then, data were analyzed using SPSS Version 15. Words were presented for 500 ms, and the subjects were asked to answer as quickly as possible. The interval between the two consecutive stimuli was randomized (2,000 ms to 3,000 ms), so that participants could not anticipate the initiation of stimuli. All reactions with response delays longer than 3,500 ms were discarded, because they exceeded the interval time between the two stimuli.

### Experimental Procedures

Dual-task methodology is a testing model that necessitates a person to carry out two tasks concurrently.<sup>30</sup> In order to assess dual-task interference, the most current approach is to compare dual-task performance in both postural and cognitive tasks against their baseline performance, and to investigate interference by examining interactions between dual-task components.<sup>31,32</sup> In the present study, 4 levels of postural difficulty (level 6 with eyes-open, level 6 with eyes-closed, level 8 with eyes-open, and level 8 with eyes-closed) were combined with 2 levels of cognitive difficulty (with and without cognitive task). Therefore, each subject completed 8 experimental conditions. In no-cognitive (single task) condition, participants were instructed to maintain the platform stable for a 30-second data collection period. For dual-task conditions, participants performed the cognitive task while attempting to maintain postural stability. Experimental condition combinations (stability level, eyes open/closed, cognitive difficulty) were randomized for each subject. During the first (test) session, each condition within the 8 randomized conditions was repeated four times, with one minute rest between trials to measure intra-session reliability. Then the second (retest) session was presented with the same protocol three to five days later.

For the sake of familiarization, auditory Stroop and dynamic postural tasks were practiced three times by the participants. The entire experiment lasted approximately 120 minutes for each subject. To assess intersession reliability of the BBS® measures, the subjects were retested in a separate session 3 to 5 days later. The order of testing conditions in both sessions was randomized but the other test situations were similar. Therefore, standardized testing conditions were used to estimate the test-retest reliability.

### Data Analysis

Paired t-tests were used to compare the differences between stability scores in test and retest sessions in order to explore the presence or absence of any systematic bias.<sup>33</sup> For the intra-session reliability of stability indices, reaction times, and error ratios, the 4 trials of each condition were used to calculate reliability. For the test-retest reliability, the 4 trials for each condition were averaged (in session 1 and session 2).

Relative intra- and inter-session reliabilities were calculated using a 2-way random model of intraclass correlation coefficient ( $ICC_{2,4}$ ) described by Shrout and Fleiss.<sup>34</sup> Munro's classification for reliability coefficients was utilized to determine the extent of reliability.<sup>35</sup> According to this classification, criteria ranges for reliability are as follows: 0.00 to 0.25- little, if any correlation; 0.26 to 0.49- low correlation; 0.50 to 0.69- moderate correlation; 0.70 to 0.89- high correlation and 0.90 to 1.00- very high correlation. In order to assess absolute reliability, the standard error of measurement ( $SEM = \text{the square-root of the mean-square error term}$ ) and 95% confidence intervals (CI) were computed to make an estimate of the amount of error associated with the measurement in the same units as the measurement.<sup>33,36</sup> To assess the change that could be considered clinically significant between two times of measurement, the minimal detectable change (MDC) was determined as 95% CI of SEM of a stability index measure ( $1.96 SEM$ ).<sup>36</sup> Moreover, the coefficient of variation (CV) was settled for pointing out of similarities and differences of absolute reliability between stability indices ( $[SD/\text{mean}] \times 100$ ).<sup>33</sup> All significance levels were set at  $p < 0.05$ .

### RESULTS

There was no statistically significant difference in age ( $p = 0.82$ ), weight ( $p = 0.53$ ), height ( $p = 0.97$ ),

Tegner's sport activity level ( $p = 0.46$ ), and sex distribution ( $p = 0.76$ ) between the two groups. Table 1 and 2 represent mean scores and standard deviations of Biodex® stability measures, reaction times and error ratios for all testing conditions. Also, there was no significant difference between test and retest mean scores for the above-mentioned parameters, which demonstrates no systematic bias ( $p > 0.05$ ).

In general, moderate to high levels of reliability for postural performance, measures in ACLR and control groups respectively, were found. The intrasession ICCs of initial test session ranged from 0.80 to 0.92 (ACLR) and 0.67 to 0.95 (controls), ICCs of retest session ranged from 0.81 to 0.91 and 0.83 to 0.93, and intersession ICCs ranged from 0.55 to 0.91 and 0.64 to 0.87 for OSI. Intrasession ICCs of initial test session ranged from 0.73 to 0.90 (ACLR) and 0.62 to 0.90 (controls), ICCs of retest session ranged from 0.73 to 0.90 and 0.53 to 0.90, and intersession ICCs ranged from 0.55 to 0.79 and 0.46 to 0.89 for APSI. Intrasession ICCs of initial test session ranged from 0.83 to 0.95 (ACLR) and 0.71 to 0.95 (controls), ICCs of retest session ranged from 0.83 to 0.94 and 0.87 to 0.93, and intersession ICCs ranged from 0.72 to 0.96 and 0.75 to 0.92 for MLSI.

The ranges of SEM for postural performance, in ACLR and control groups respectively, were from 0.46 to 1.25 and 0.31 to 0.70 for OSI, from 0.19 to 1.09 and 0.26 to 0.65 for APSI, and from 0.22 to 0.94 and 0.19 to 0.46 for MLSI.

The ranges of CV for postural performance, in ACLR and control groups respectively, were from 20.82% to 49.79% and 20.94% to 29.39% for OSI, from 19.55% to 40.69% and 18.89% to 30.26% for APSI, and from 15.52% to 37.27% and 27.10% to 37.33% for MLSI.

Finally, the ranges of MDC values for postural performance, in ACLR and control groups respectively, were from 0.90 to 2.45 and 0.61 to 1.37 for OSI, from 0.37 to 2.14 and 0.51 to 1.27 for APSI, and from 0.43 to 1.84 and 0.37 to 0.90 for MLSI (Table 3).

It is notable that a moderate to high level of reliability for cognitive performance in ACLR and control groups respectively was also displayed, with ICCs of initial test session for reaction time ranging from 0.92 to 0.95 (ACLR) and 0.80 to 0.92 (controls), ICCs of the retest session ranged from 0.89 to 0.98 and



**Table 1.** Descriptive data for test-retest Biodex Stability System Measures Made under Different Conditions of Postural and Cognitive Difficulty in a Sample of Individuals with ACL-R ( $n = 15$ ) and Healthy Subjects ( $n = 15$ ). Values are mean  $\pm$  standard deviation (SD).  $p$  refers to  $p$ -values of paired  $t$ -test on test-retest differences.

Variables				ACL-R Group					Healthy Group				
Level	Task	Eyes	Stability Index	Test		Retest			Test		Retest		
				Mean	SD	Mean	SD	<i>p</i>	Mean	SD	Mean	SD	<i>p</i>
8	Single	Open	Anterior-Posterior	2.20	0.70	2.84	0.81	0.05	1.82	0.36	2.31	0.36	0.06
			Medial-Lateral	2.12	0.81	2.13	0.60	0.93	1.87	0.63	1.82	0.73	0.75
			Overall	3.03	0.77	3.04	0.66	0.98	2.54	0.54	2.45	0.65	0.45
		Closed	Anterior-Posterior	4.12	1.22	3.33	0.93	0.06	3.71	0.87	3.06	0.66	0.09
			Medial-Lateral	3.05	1.03	2.87	0.90	0.07	2.74	0.82	2.47	0.63	0.05
			Overall	5.11	1.38	4.33	1.04	0.06	4.54	1.02	3.84	0.80	0.07
	Dual	Open	Anterior-Posterior	2.22	0.73	2.15	0.61	0.71	2.06	0.58	2.70	0.72	0.05
			Medial-Lateral	2.22	0.76	2.21	0.70	0.95	2.04	0.70	1.83	0.64	0.16
			Overall	3.11	0.92	3.04	0.61	0.74	2.84	0.81	2.54	0.77	0.24
		Closed	Anterior-Posterior	3.77	1.39	3.52	0.97	0.36	3.45	0.78	2.98	0.73	0.07
			Medial-Lateral	3.00	0.69	2.80	0.76	0.20	2.70	0.70	2.45	0.77	0.16
			Overall	4.77	1.39	4.47	0.92	0.25	4.32	0.82	3.76	0.93	0.05
6	Single	Open	Anterior-Posterior	2.42	0.84	2.24	0.63	0.44	2.34	0.77	2.18	0.60	0.14
			Medial-Lateral	2.24	0.70	2.32	0.69	0.52	2.32	0.71	2.04	0.76	0.06
			Overall	3.23	0.90	3.19	0.66	0.84	3.25	0.83	2.95	0.86	0.05
		Closed	Anterior-Posterior	5.63	1.69	6.54	1.45	0.07	2.33	0.66	3.95	1.10	0.07
			Medial-Lateral	3.87	1.30	3.75	1.53	0.74	2.27	0.97	2.89	0.95	0.07
			Overall	6.84	1.76	5.96	1.98	0.08	3.23	0.93	4.80	1.33	0.06
	Dual	Open	Anterior-Posterior	2.85	1.23	2.29	0.65	0.08	4.56	0.99	3.13	0.65	0.05
			Medial-Lateral	2.57	0.91	2.46	0.82	0.36	3.48	1.41	2.04	0.70	0.07
			Overall	3.82	1.26	3.30	0.80	0.06	5.67	1.55	2.86	0.62	0.05
		Closed	Anterior-Posterior	5.20	1.97	4.27	1.20	0.10	4.42	1.53	3.99	1.45	0.08
			Medial-Lateral	3.96	1.09	3.83	1.05	0.54	3.22	1.06	3.13	0.93	0.07
			Overall	6.52	1.96	5.70	1.26	0.15	5.40	1.74	4.98	1.64	0.05

**Table 2.** Descriptive data for test-retest Cognitive Test Measures Made under Different Conditions of Postural and Cognitive Difficulty in a Sample of Individuals with ACL-R ( $n = 15$ ) and Healthy Subjects ( $n = 15$ ). Values are mean  $\pm$  standard deviation (SD).  $p$  refers to  $p$ -values of paired  $t$ -test on test-retest differences.

Variables			ACL-R Group						Healthy Group			
Level	Task	Cognitive Test	Test		Retest		p	Test		Retest		
			Mean	SD	Mean	SD		SD	Mean	SD	Mean	p
8	Open	Reaction Time	0.88	0.37	0.82	0.38	0.39	0.67	0.21	0.63	0.18	0.38
		Error Ratio	0.27	0.19	0.15	0.15	0.05	0.10	0.12	0.07	0.08	0.47
	Closed	Reaction Time	0.87	0.38	0.89	0.43	0.76	0.68	0.18	0.62	0.14	0.13
		Error Ratio	0.25	0.19	0.18	0.14	0.12	0.13	0.15	0.07	0.11	0.22
6	Open	Reaction Time	0.95	0.50	0.85	0.43	0.06	0.62	0.13	0.60	0.11	0.54
		Error Ratio	0.26	0.20	0.13	0.15	0.06	0.08	0.09	0.06	0.06	0.22
	Closed	Reaction Time	0.90	0.38	0.89	0.37	0.94	0.66	0.20	0.64	0.15	0.59
		Error Ratio	0.22	0.20	0.18	0.17	0.39	0.12	0.10	0.08	0.07	0.09

0.80 to 0.92, and intersession ICCs ranging from 0.87 to 0.95 and 0.68 to 0.81. ICCs of error ratio for initial test session ranged from 0.72 to 0.88 (ACLR) and 0.61 to 0.83 (controls), ICCs of retest session ranged from 0.73 to 0.87 and 0.54 to 0.79, intersession ICCs ranged from 0.42 to 0.64 and 0.54 to 0.70.

Furthermore, the range of SEM for cognitive performance, in ACLR and control groups respectively, was

from 0.12 to 0.18 and 0.07 to 0.13 for reaction time (milliseconds), and from 0.11 to 0.15 and 0.05 to 0.11 for error ratio. Moreover, the range of CV for cognitive performance, in ACLR and control groups respectively, was from 41.11% to 51.14% and 20.00% to 31.25% for reaction time, and from 70.00% to 79.00% and 11.11% to 78.18% for error ratio. Finally, the range of MDC values for cognitive performance, in ACLR and control groups respectively, was from 0.24

**Table 3.** Intra- and Intersession Reliability of the Biodex Stability System Measures Made under Different Conditions of Postural and Cognitive Difficulty in a Sample of Individuals with ACLR (n = 15) and Healthy subjects (n = 15). [ICC, intraclass correlation coefficient; SEM, standard error of measurement; MDC, minimal detectable change]

Variables				ACLR Group					Healthy Group						
Level	Task	Eyes	Stability Index	Intrasession		Intersession				Intrasession		Intersession			
				Test ICC	Retest ICC	ICC	SEM	MDC	CV	Test ICC	Retest ICC	ICC	SEM	MDC	CV
8	Single	Open	Anterior-Posterior	0.79	0.84	0.61	0.19	0.37	19.55%	0.62	0.53	0.46	0.35	0.69	18.89%
			Medial-Lateral	0.93	0.86	0.78	0.41	0.80	32.86%	0.83	0.91	0.77	0.40	0.78	35.68%
			Overall	0.86	0.81	0.55	0.57	1.12	23.76%	0.72	0.86	0.80	0.31	0.61	23.20%
		Closed	Anterior-Posterior	0.73	0.85	0.72	0.57	1.12	28.95%	0.80	0.77	0.53	0.55	1.08	22.06%
			Medial-Lateral	0.93	0.92	0.96	0.22	0.43	32.77%	0.89	0.90	0.91	0.19	0.37	27.10%
			Overall	0.83	0.87	0.91	0.47	0.92	23.40%	0.86	0.89	0.71	0.47	0.92	21.14%
	Dual	Open	Anterior-Posterior	0.78	0.87	0.60	0.51	1.00	30.73%	0.79	0.87	0.54	0.57	1.12	29.29%
			Medial-Lateral	0.90	0.94	0.87	0.70	1.37	22.48%	0.92	0.91	0.77	0.40	0.78	33.33%
			Overall	0.90	0.91	0.75	0.46	0.90	20.82%	0.95	0.93	0.68	0.65	1.27	27.68%
		Closed	Anterior-Posterior	0.80	0.76	0.79	0.66	1.29	40.69%	0.69	0.87	0.55	0.65	1.27	22.98%
			Medial-Lateral	0.83	0.93	0.80	0.41	0.80	15.52%	0.71	0.90	0.75	0.46	0.90	27.69%
			Overall	0.85	0.81	0.79	0.61	1.20	49.79%	0.67	0.89	0.64	0.70	1.37	20.94%
6	Single	Open	Anterior-Posterior	0.85	0.87	0.69	0.61	1.20	32.46%	0.79	0.62	0.89	0.26	0.51	29.65%
			Medial-Lateral	0.88	0.89	0.75	0.32	0.63	21.43%	0.88	0.87	0.86	0.34	0.67	33.49%
			Overall	0.87	0.88	0.76	0.47	0.92	25.32%	0.83	0.88	0.86	0.39	0.76	27.04%
		Closed	Anterior-Posterior	0.78	0.73	0.78	1.09	2.14	36.58%	0.90	0.85	0.83	0.59	1.16	26.36%
			Medial-Lateral	0.90	0.92	0.72	0.94	1.84	34.13%	0.90	0.90	0.92	0.32	0.63	37.33%
			Overall	0.80	0.90	0.67	1.25	2.45	28.93%	0.92	0.90	0.87	0.60	1.18	24.92%
	Dual	Open	Anterior-Posterior	0.89	0.88	0.55	0.73	1.43	32.49%	0.82	0.64	0.51	0.52	1.02	29.89%
			Medial-Lateral	0.95	0.91	0.93	0.32	0.63	27.44%	0.95	0.93	0.91	0.27	0.53	33.83%
			Overall	0.92	0.89	0.76	0.52	1.02	26.35%	0.93	0.83	0.73	0.43	0.84	29.39%
		Closed	Anterior-Posterior	0.90	0.90	0.61	0.35	0.69	29.01%	0.72	0.90	0.78	0.53	1.04	30.26%
			Medial-Lateral	0.83	0.83	0.83	0.59	1.16	37.27%	0.93	0.88	0.88	0.37	0.73	32.13%
			Overall	0.88	0.86	0.63	1.24	2.43	29.22%	0.89	0.92	0.86	0.55	1.08	29.04%

to 0.35 and 0.14 to 0.25 for reaction time, and from 0.22 to 0.29 and 0.10 to 0.22 for error ratio (Table 4).

## DISCUSSION

The present study examined the inter-session and intra-session reliability of the BBS® in subjects with and without ACLR during dual-task performance. To the authors' knowledge, there has been no study to date on the reliability of BBS® measurements in subjects with and without ACLR using a dual-task methodology. BBS® postural stability measures were reliable and may be useful for measuring the postural balance and monitoring programs for improvement of postural control in ACLR knees. However,

there is no evidence about the validity of BBS® measures and to the authors knowledge, it has not been evaluated in any related article.

The results of this study suggest that ICC values were higher for MLSI compared to OSI and APSI for different conditions of postural and cognitive task difficulty. Additionally, ICC values were higher for reaction times in comparison with error ratios in all tested conditions. Generally, the results showed a moderate to high level of reliability for the measurements of stability indices and cognitive outputs in thorough trials.

Hinman<sup>26</sup> determined higher reliability of BBS® measures in elderly when more challenging postural



**Table 4.** Intra- and Intersession Reliability of the Cognitive Test Measures Made under Different Conditions of Postural and Cognitive Difficulty in a Sample of Individuals with ACLR (n = 15) and Healthy subjects (n = 15). [CV, coefficient of variation; ICC, intraclass correlation coefficient; SEM, standard error of measurement; MDC minimal detectable change].

Variables			ACLR Group							Healthy Group					
Level	Task	Cognitive Test	Intrasession		Intersession				Intrasession		Intersession				
			Test ICC	Retest ICC	ICC	SEM	MDC	CV	Test ICC	Retest ICC	ICC	SEM	MDC	CV	
8	Open	Reaction Time	0.92	0.95	0.87	0.18	0.35	43.53%	0.91	0.92	0.74	0.13	0.25	31.25%	
		Error Ratio	0.72	0.87	0.56	0.15	0.29	70.00%	0.83	0.57	0.58	0.08	0.16	11.11%	
		Reaction Time	0.93	0.96	0.89	0.18	0.35	45.98%	0.87	0.89	0.68	0.11	0.22	25.00%	
	Closed	Error Ratio	0.88	0.84	0.64	0.11	0.22	76.19%	0.83	0.64	0.54	0.11	0.22	78.18%	
		Reaction Time	0.95	0.98	0.95	0.12	0.24	51.14%	0.80	0.72	0.81	0.07	0.14	20.00%	
		Error Ratio	0.81	0.84	0.42	0.15	0.29	79.00%	0.62	0.79	0.60	0.07	0.14	75.00%	
6	Open	Reaction Time	0.93	0.89	0.90	0.16	0.31	41.11%	0.92	0.80	0.73	0.12	0.24	28.57%	
	Closed	Error Ratio	0.82	0.73	0.55	0.14	0.27	70.00%	0.61	0.54	0.74	0.05	0.10	61.82%	
		Reaction Time													

conditions were displayed which is consistent with the current findings. Single-limb stance on a movable platform with eyes closed during dual-tasking may be at a level of difficulty that might lead to greater variability of balance performance among subjects with ACLR. Thus, this condition would likely result in higher ICC values than those in healthy subjects in most testing conditions. However, in the study of Hinman et al,<sup>26</sup> the balance test duration was exactly the same as the current protocol (30 seconds). However, their test and retest sessions were performed on the same day with an interval of 30-60 seconds. Moreover, Hinman<sup>26</sup> developed the test with subjects wearing hard- or soft-soled shoes while in the current study the participants were asked to stand barefoot on the Biodex platform. In the current protocol, the time between evaluation times was different (3 to 5 days) and two different levels of stability on the BBS® were employed, Level 8 (the same stability level used in the study of Baldwin et al.<sup>37</sup> and Level 6. Furthermore, Hinman<sup>26</sup> only analyzed the relative reliability but not absolute reliability as recommended by recent studies.<sup>38,39</sup>

Generally speaking, reliability measures achieved in this study for all stability indices (Table 2) were higher than those reported by Pincivero et al<sup>23</sup> and lower than those of Cachupe et al<sup>22</sup> in single task conditions. Also, in single task conditions, the current

SEMs, similar to those of Parraca et al,<sup>39</sup> were better than those in the previous studies.<sup>22</sup> Use of different test protocols among studies, makes it impossible to directly compare their results.

There is little evidence with respect to the reliability of auditory Stroop task.<sup>40</sup> Relative and absolute reliability with correlation coefficients ranging from 0.84 to 0.94, and SEMs ranging 0.047 to 0.219 were reported by Jerger et al.<sup>40</sup> These values were calculated for reaction time task in five different conditions of the auditory Stroop test in normal children. The observed differences between current reliability results and the latter study could be explained by the different target populations and the varied auditory Stroop tasks.

The most important characteristic of the ICC is its sensitivity to between-subject variability.<sup>33</sup> In the immediate surroundings of high between-subject variability, a large ICC can be achieved even if the absolute reliability is low.<sup>33</sup> The SEM, an estimate of error for interpreting an individual's test score, is directly related to the reliability of a test; that is, the larger the SEM, the lower the reliability of the test and the less precision in the scores obtained. The CV expresses the standard deviation as a percentage of the sample mean which allows comparison of variability estimates eliminating the effect of mean values.<sup>34</sup> The estimated MDC of each stability index measure provides information



about the amount of measurement error that should be taken into account when setting the least significant changes expected following two consecutive measurements.<sup>36,41</sup> The current reliability results could not be generalized to other athletes' populations and other dynamic and static postural conditions. However, the results of this research may act as a basis for improving the reliability of the evaluation of balance in patients with ACL reconstructed knees, and better describing the deficit(s) discovered in balance especially during dual-tasking. Dual-task training may have benefits over single-task training if the purpose of practice is to enhance postural control performance. However, this assertion requires further investigation in future.

To extend the work completed in the present study, future researchers might investigate (a) the reliability of BBS® measures among groups of varying history of injury, activity levels, and functional capacity; (b) the reliability of BBS® measures among athletes who participate in different sports; (c) the reliability of BBS® measures at different levels of platform stability and for different length trials; (d) the reliability of BBS® measures during different cognitive demands.

## CONCLUSIONS

Biodex® measures of postural stability, as well as reaction times and error ratios during the auditory Stroop task have been found to be reliable during testing of a single-leg postural control protocol, utilizing multiple test constructs, both within a single session and between sessions. Therefore, these procedures may be recommended for obtaining reliable measures of dynamic postural assessment in ACL reconstructed athletes, especially in dual-task conditions.

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